TUBE COLD DRAWING PROCESSES USING NUMERICAL SIMULATION

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Abstract

Cold drawing is the final process of plastic deformation in the manufacture of precision steel seamless tubes. This particular technology is utilities by multiple drawing operations (sequences) with intermediate heat treatment. The different drawing methods are differentiate according specification of the inner diameter of the tube. Hollow sinking process is simply drawing the tube through and reducing the outside and inside diameters without using an internal support (tool). Plug drawing is used to achieve wall thickness and inner diameter. According to the shape it is possible to distinguish the plugs on the conical and cylindrical. A modern approach to solving complex technological issues is the use of numerical simulations based on the finite element method. In this paper, stress-strain states describing the flow of material will be analysed, as well as the geometry of tribological pairs of forming tools with respect to the drawing force. The results are verified in technology in order to improvement production and reduce economic costs.

Keywords: Seamless steel tube, FEM, numerical simulation, cold drawing, drawing force

1. INTRODUCTION

At Zeleziarne Podbrezova a. s. (ZP), the drawing process of precision seamless steel tubes has a long tradition. Already in 1968, the construction of a new tube plant began. The tubes have been produced at ZP by drawing technology since 1971. After long time, this process has undergone great changes. Today, ZP is a major European producer of hot-rolled and cold-drawn seamless steel tubes. At present, it is possible to talk about high-tech technology. The tubes are drawn to the final dimensions according to the customer´s requirements. For this particular technology, a hot rolled seamless steel tube serves as a feedstock for multiple cold drawing operations with intermediate heat treatment. The reduction of the outer diameter and wall thickness must be set correctly for every pass. The aim is determine the lowest number passes because of low economy costs. In this technology, drawing with plug and hollow sinking are used. In the first passes, where the outer diameter and wall thickness is reduced, the drawing with the fixed plug is used. The fixed cylindrical or fixed conical plug is utilized depending on the wall thickness of input feedstock. The conical plug enables to use higher drawing velocity thanks to its geometry which provides better flow of material. Hollow sinking is a final process in which the wall thickness stays the same and the outer dimension is reduced [1-3]. An efficient way to optimize a technological process is to use numerical simulations based on the finite element method. DEFORM 3D simulations allow you to achieve real-time results with the least cost. This approach is very modern and sophisticated. For the credibility of numerical simulations, validation with a technology test is required. By means of numerical simulations it is possible to "look" into the process of plastic deformation and to observe various physical fields in the modelled object, e.g. mechanical stress, deformation, strain rate, risk of material failure, material flow throughout the modelled volume [4]. After agreement of the achieved results it is possible to optimize the technological process.

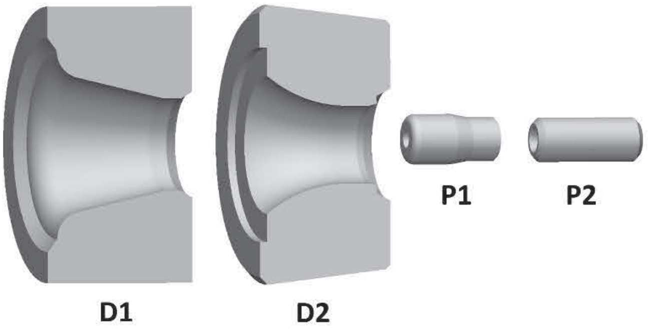

Figure 1 Forming tools

In this paper, combination of dual forming tools was calculated and compared by means of numerical simulations based on the selected variables (**Figure 1**). The optimum combinations are successfully implemented in technology. Drawing die D1 is characterized by feed angle φ = 26°. Geometry of drawing die D2 is characterized by radius R = 35mm. The forming part of plug P1 is defined by drawing angle δ = 0°8´, while the plug P2 has an ideal cylindrical shape.

2. MATERIAL, SIMULATION AND EXPERIMENT

Material data - flow stresses for steel grade E235 were defined by compress plastometric exams at different strain rates (**Figure 2**). The material temperature was 20 °C and no heat transfer between the material and the tools was considered. Friction was included in the model being a shear-type with the value f = 0.05. The friction coefficient depends on a large number of factors: chemical preparation, lubrication, surface roughness and others [5]. For numerical simulations we use the value f = 0.04 - 0.08. This value has been validated by the drawing force measured in technology and by numerical simulation as published in [6]. The friction coeficient is piece - wise linear dependent on drawing force (**Figure 3**). Drawing velocity was also constant and the same in all simulation v = 50 mm/s. The tube was defined as a plastic object, which is suitable for modelling of cold forming processes under certain conditions. In order to shorten the calculation time, it is possible to use the 1° symmetry for the modelled domain, because of symmetry plane. The tube was defined by FEM brick mesh. The wall thickness was described by ten elements due to high precision. In case of plug drawing was calculated pass with entry dimension of the tube 25 mm (outer diameter) × 2.5 mm to final dimension 20 × 2 mm. In case of hollow sinking was calculated pass 25 × 2 mm to 20 × 2.5 mm.

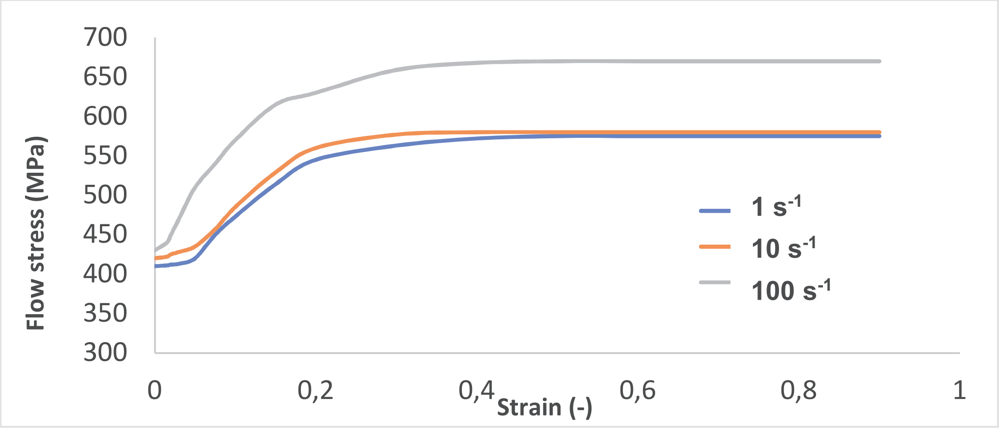

Figure 2 Flow stress steel grade E235

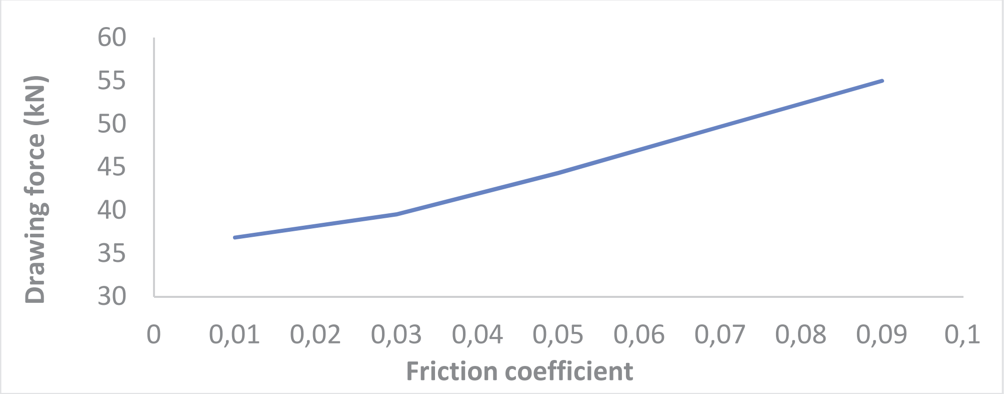

Figure 3 Drawing force dependence of the friction coefficient

3. RESULTS AND DISCUSSION

Table 1 shows the values from numerical simulations for the various combination of the tools for cold drawing. The results were evaluated in postprocessor Deform 3D in a steady state of the simulation (Eulerian point of view), which inherently oscillated due to a numerical nature of the model. The lowest drawing force was recorded with the tool combination D1 + P1 and also the lowest plug load in axial direction. The combination of forming tools have influence on final wall thickness of the tube. The strictly dimension was achieved only by the first combination. The wall thickness was for another three combinations thin as required. Another situation was in the hollow sinking process, the wall thickness become thicken.

Table 1 Numerical simulation results

Combination of forming tools	Plug load in axial direction [kN]	Drawing force [kN]	Wall thickness [mm]
D1 + P1	0.35	48.0	2.00
D1 + P2	0.74	50.9	1.92
D2 + P1	0.91	52.0	1.98
D2 + P2	1.23	52.1	1.99
D1	-	38.5	2.60
D2	-	34.0	2.58

Also, the flow of material was analysed by stress distribution. The similar stresses are achieved in deformation zone in both cases of tool combinations. However, when D1 + P2 is combined, higher stresses (σ = < 496; 579 > [MPa]) are obtained after leaving the tube of this section (**Figure 4**). This caused a larger contact area of the plug and the inner surface of the tube. On the final dimensions, this was reflected in a reduction in the wall thickness of the *wt* = 1.92mm. Thickening of the wall thickness during the hollow sinking process was also recorded in the works [7-9].

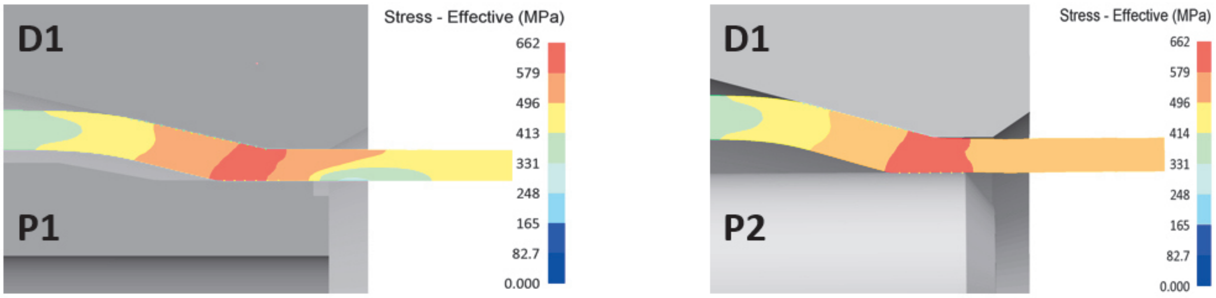

Figure 4 Stress in longitudinal section of the tube in steady state

3.1. Position of the plug with respect to die

A very important factor in plug drawing is the plug position with respect the die. Via numerical simulations, we tried to estimate what position is most suitable for application in industry technology. For this study, the combination of D1 + P1 and D1 + P2 was selected. In each case, the three plug positions (**Figure 5**) were simulated. The simulated values are compared in **Table 2**.

Table 2 Plug load in various position with respect to die

Plug load (Forming tools)	Plug position		
	-2 mm	0 mm	+2 mm
Plug load (D1 + P1) [kN]	0.32	0.35	0.34
Plug load (D1 + P2) [kN]	0.37	0.75	0.96

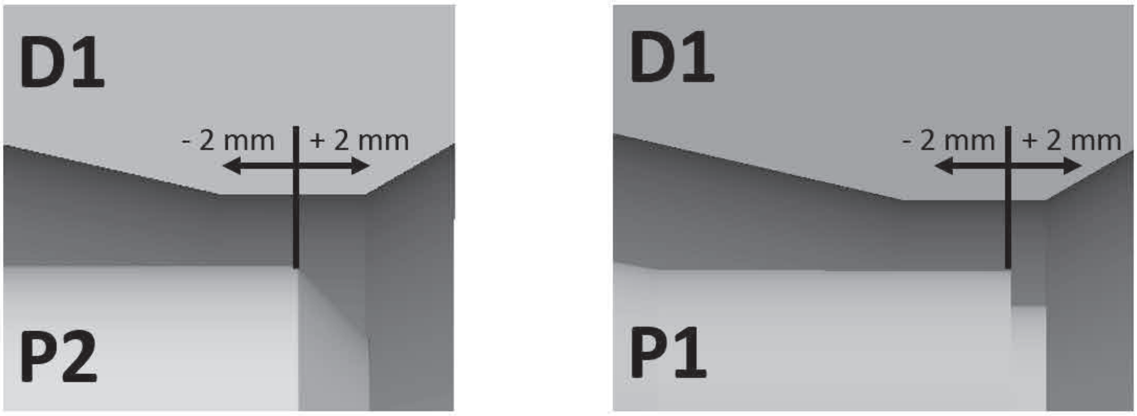

Figure 5 Position of the plug with respect to the die

There were no significant differences between the plug loading in the axial direction for the tools combination P1 + D1. This is because the contact area between the tools and the tube has not changed significantly. Also, the fact that the plug geometry is not straight but conical (**Figure 6**). While the position of the cylindrical plug also significantly influenced the contact area and thus the plug loading.

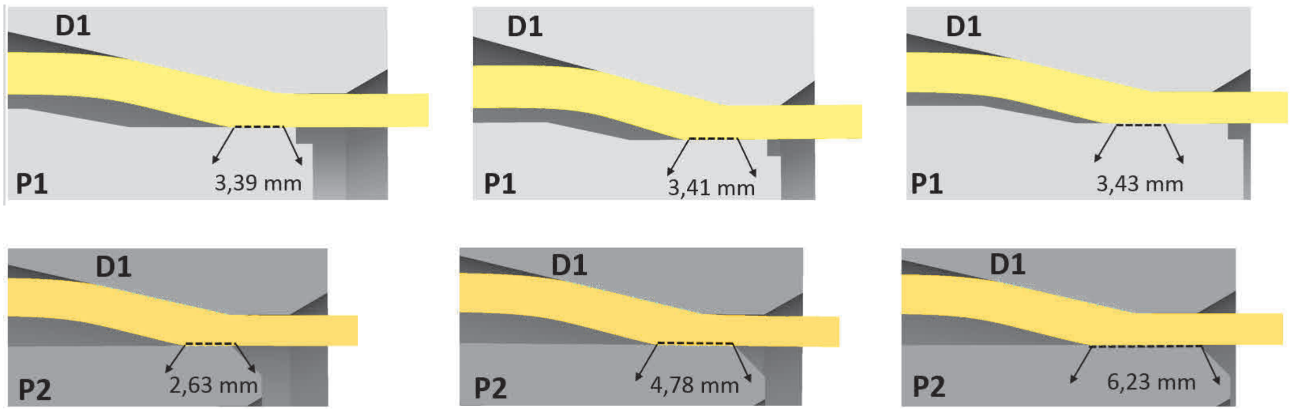

Figure 6 Position of the plug with respect to the die with marking contact area

4. CONCLUSION

Via numerical simulations it is possible to solve technological issues. This approach is helpful for recognize the difference of material flow in the individual types of drawing. Another advantage is monitoring the load of the tool, which can be economical for tool wear in high tube production. The results and settings are then applied to manufacturing practice. Significant results in solving technological issues have already been achieved in the work [10]. Thus, the company carries out a smaller number of technological tests. The low value of the drawing force was achieved by an effective combination and positioning of the forming tools.

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